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OPEN LOOP OPERATION OF SWITCHED RELUCTANCE MOTOR WITH R DUMP CONVERTER

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ABSTRACT

The switched reluctance motors had gained more attention among the variable speed drives due to its inherent simplicity and low cost. It is an electronically commutated motor and need to be driven from a converter. The excitation of the different phases of the converter are dependent on the rotor position. This paper presents the simulation of the Open loop control of a 6/4 switched reluctance motor driven with R dump using speed position sensing. Here the gate signals are derived from the speed output of the motor.

KEYWORDS: Switched Reluctance Motor, R Dump Converter, Speed Position Sensing, Open Loop Control

INTRODUCTION

The low cost, simple construction of switched reluctance motor, with fault tolerance and ability to stand high temperatures makes its very suitable for the automotive application. It can also achieve very high speeds due of the absence of conductors or magnets on the rotor. However, It cannot be run directly from a dc bus or an ac line as it is an electronically commutated drive. Its double salient structure causes strong nonlinear magnetic characteristics making its analysis and control very complicated.

The conventional converter used to run the switched reluctance motor is the asymmetric converter and is the most flexible one. When power is applied to the phase windings, the rotor magnetic reluctance develops a force that makes the rotor pole align with the nearest stator pole. An electronic control system switches on the windings of successive stator poles in sequence so that the magnetic field of the stator leads the rotor pole to maintain rotation. The excitation of the phase windings of the machine is dependent on its rotor position. Gate signals are derived from the rotor position. In this paper the speed signal is used to generate the switching signal for the converter rather than the teta output [1].

SWITCHED RELUCTANCE MOTOR

Basic Features of Switched Reluctance Motor

The Switched Reluctance motor is an electric machine that converts the reluctance torque into mechanical power. SRM is a double salient structure with salient pole on both stator and rotor contributing to high output torque. The reluctance torque is produced by the alignment tendency of poles. The rotor will shift to a position of minimum reluctance and thus maximizing the inductance of the excited winding. The rotor is basically a piece of steel shaped to form salient poles but there are no windings or permanent magnets on the rotor. Hence it is the only motor type with both salient pole rotor and

stator. The SRM is a reliable and a low cost variable speed drive due to its inherent simplicity [2]. The stator houses a set of coils or windings per salient pole connected in series between the opposing poles. The concentrically wound coils without any overlap between the phases, results in little mutual inductance between them and ensures a greater portion of copper to be used as active length. The SRM has unequal number of poles on stator and the rotor to avoid the possibility of the rotor to be in a state that it cannot produce initial torque, when the rotor and the stator poles are in alignment. Figure 1 shows the construction of switched reluctance motor with its stator core, windings A, B and C, and the rotor core [3].

Figure 1: Construction of Switched Reluctance Motor

The iron rotor is attracted to the energized stator pole and as a result of this attraction, torque is produced between the electromagnet and the iron rotor. The rotor forms a magnetic circuit with the excited stator pole whose reluctance decreases as the rotor aligns with the stator pole. When the rotor is completely aligned with the stator the gap between the rotor and stator is very small where the reluctance is at its minimum as shown in Figure 2.

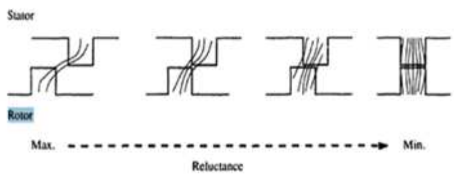

Figure 2: Variation of Reluctance with Rotor Position

The inductance of the energized winding varies as the rotor rotates. It will be very low when the rotor is unaligned and the current will increase rapidly. The inductance will be very large with decreased slope decreases when the rotor is aligned with the stator. The causes of the torque ripple include the geometric structure including doubly salient motor, concentrated phase windings around the stator poles and the working modes which are necessity of magnetic saturation in order to maximize the torque per mass ratio and pulsed magnetic field obtained by feeding successively the different stator windings [4].

The energy conversion in a SRM depends on the magnetic interaction of the rotor and stator, which changes with relative angular position. The aligned position occurs for a given phase when a pair of rotor poles is exactly aligned with the stator poles of that phase. Conversely, the unaligned position occurs when the axis equidistant between the pairs of rotor poles (interpolar axis) is exactly aligned with stator poles of a given phase rotor poles. All other positions are referred to as a misaligned position. When the rotor poles are symmetrically misaligned with the stator poles of a phase, it is said to be the unaligned position and at this position the phase has minimum inductance. Figure 3 shows the aligned and misaligned position of rotor and stator cores with respect to an axis.

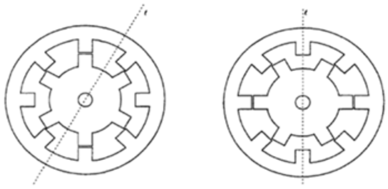

Figure 3: Aligned and Unaligned Positions for SRM

A minimum rotor losses and low switching losses in the controller enable high overall system efficiency over wide control range. Hence, SR motors are not designed and optimized to a fixed synchronous speed. Also this produces a higher power (torque) to weight ratio as standard ac or dc motors. Very high starting torque is realizable in SRM permitting prolonged operation in the stall condition because of its low rotor losses. The simple construction of the magnet free, brushless SR Motor makes it easier to be integrated with the driven machine than with conventional motors.

Equivalent Circuit of SRM

The equivalent circuit for SRM consists of resistance and inductance ignoring the effect of magnetic saturation, , leakage flux, the mutual coupling of phases and the fringing flux around the pole corners. The three differential equations namely, the voltage equation, the motional equation and the electromagnetic torque equation describes the linear analytical model of the SRM [3]. The voltage equation is:

$$V = R \cdot i + \frac{d\lambda(\theta, i)}{dt},$$

An equivalent circuit of the SRM is shown in Figure 4, where V is the applied phase voltage to phase, R is the phase resistance, and e is back emf. Back emf, e is the function of phase current and rotor position, and λ can be expressed as the product of inductance and winding current:

$$\lambda(\theta, i) = L(\theta, i) \cdot i,$$

And from the above equations, the function can be rewritten as:

$$V = R \cdot i + \frac{d\lambda(\theta, i)}{di} \cdot \frac{di}{dt} + \frac{d\lambda(\theta, i)}{d\theta} \cdot \frac{d\theta}{dt}$$

The Electromagnetic torque equation is given by,

$$T_e(i, \theta) = T_L + B\omega + J\frac{d\omega}{dt}$$

Where T_e is electromagnetic torque, T_L is the load torque, B is viscous coefficient and J is moment of inertia.

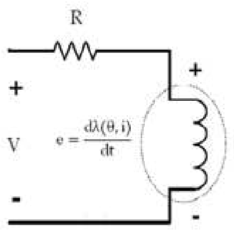

Figure 4: Equivalent Circuit of SRM

Electromagnetic torque is dependent on phase current and rotor position

$$T_e = \frac{1}{2} i^2 \frac{dL(i,\theta)}{d\theta}$$

Mechanical equation is given by,

$$\frac{1}{2} i^2 \frac{dL(i,\theta)}{d\theta} - T_L = B\omega + J\frac{d\omega}{dt}$$

CONTROL OF SWITCHED RELUCTANCE MOTOR

The power converter is a power supply unit used to apply current in each phase in coordination with the rotor position to achieve the desired operating mode and torque output. It is required to activate and commutate the motor phases. Hence, In addition to delivering energy to an electronic device from an electrical outlet, it also regulates the current to meet specific device requirements. The position detector detects the rotor position as the phase excitation pulses need to be properly synchronized to the rising region of the inductance profile for motoring operation. The controller regulates the motor performance. It derives the gate signals from the rotor position signal which may be realized by a rotor position sensor or a sensor less control procedure [5].

The SRM requires only unidirectional current to operate in all four quadrants, enabling fewer semiconductor switches to be used in the converter design and widens the range of drive circuit options as compared to other motor types requiring bi-directional or sinusoidal current. Because of the inductive nature of each phase winding, the switches must be protected from transients due to the induced voltages after commutation occurs and current must always be provided a conduction path, so freewheeling diodes or some other type of clamping mechanism will also be required.

R DUMP CONVERTER

The R dump converter is one among the single switch per phase configuration and is the simplest one.The *R*-dump converter type is shown in Figure 6 is the converter configuration with one switch and one diode per phase. Asymmetrical converters are commonly used in switched reluctance drives with two main switches and two flywheel diodes in per phase circuit.When the switch *T1* is turned off, the current freewheels through diode *D1*, charging *Cs*, and later flows through the external resistor *R* which partially dissipates the energy stored in the energized phase [6-8].

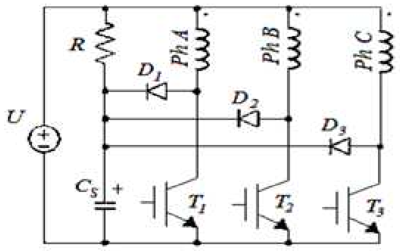

Figure 6: R Dump Converter

The design considerations such as the turn-off transient voltage have to be included in rating of the switch *T1*. If the current comes under the negative slope region of the phase inductance, negative torque will be generated, decreasing the average motoring torque. The value of resistance *R* determines the power dissipation and also the switch voltage. The stress on the switch increases with higher value of resistance *R*, and with lower value of resistance the appropriate fall time of the current increases. This converter has the disadvantage that the current in any of phases will take longer to extinguish compared to recharging the source. Also the energy dissipated in a resistor reduces the overall efficiency of the motor drive.

OPEN LOOP CONTROL OF SWITCHED RELUCTANCE MOTOR

As the switched reluctance motor is an electronically commutated machine, it need to be driven with a power electronic converter. The R dump converter is used for simulation. DC supply can be used to excite the phase windings. The open loop control of a 6/4 three phase switched reluctance motor is performed with the help of computer simulation in MATLAB software. Figure 7 shows the simulink model of the open loop control of switched reluctance motor. The excitation of the windings is dependent on the rotor position. The speed output from the motor is used to sense the position of the rotor and to derive the switching signals to drive the motor [9].

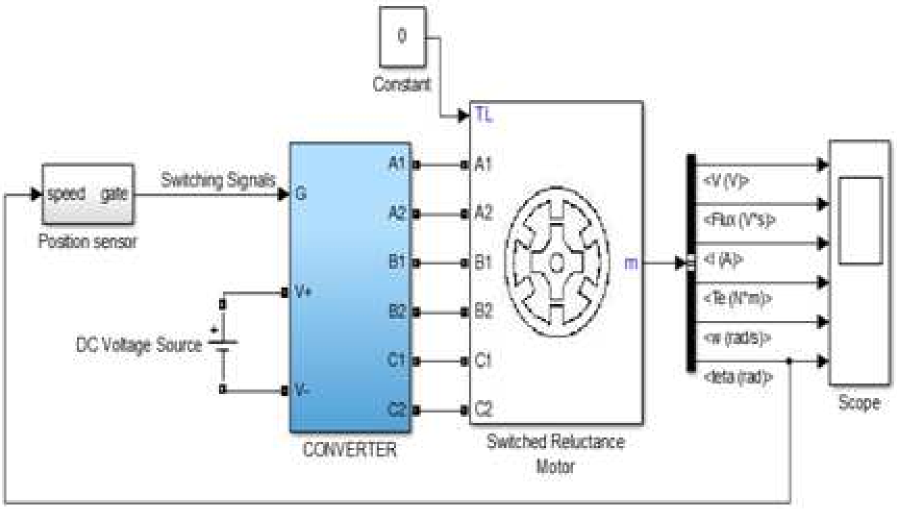

Figure 7: Simulink Model of Open Loop Control of SRM

The switched reluctance motor used for simulation is a 6/4 configuration SRM taken from MATLAB software with the block parameter specification given in Table 1 [9].

Table 1: Block Parameters of Switched Reluctance Motor

Parameter	Value
Stator resistance (ohm)	0.05

Inertia (kg.m^2)	0.05
Friction (Nm.s)	0.02
Initial speed and position (rad/s and rad)	0,0
Unaligned inductance (H)	0.67e-3
Aligned inductance (H)	23.6e-3
Maximum current (A)	450
Maximum flux linkage (Vs)	0.486

The SRM block input is the mechanical load torque in Nm which is positive for motoring and negative for generating operation. The block output of SRM is a vector containing stator voltage in Volts, Flux linkage in Vs, Stator current in A, Electromagnetic torque in Nm, Rotor speed in rad/s and rotor position in rad respectively.Simulation is run in discrete mode and the turn on and turn off angles are kept constant at 40 and 75 respectively.

R Dump Converter

The R dump converter consists of only a single diode and an IGBT switch for each phase. Each phase is excited according to the gate pulses given according to the rotor position such that each phase is excited in every 90 degree rotation of the rotor as there are 4 rotor poles. Same gate pulse is given to both the switches of the corresponding phase. When the gate pulse are high the switch of the corresponding phase is turned on and the supply voltage appears across the supply. An input voltage of 150 V is given to excite the phase windings [3].The gate signals for the switches of the corresponding phases are produced depending upon the rotor position. Figure 10 shows the gate signals for the individual phases. When the gate pulses are high the applied voltage appears across the phase windings of the corresponding phases.

PHASE ACTIVATION THROUGH SPEED POSITION SENSING

Figure 8 shows the position sensor block using the speed position sensing and Figure 9 shows the waveforms at different stages of the sensing [9-10].

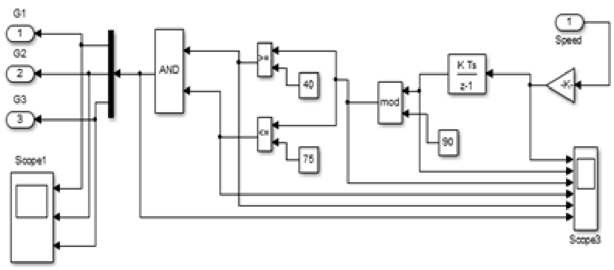

Figure 8: Simulink Model of Speed Position Sensing

The speed output from motor in rad/s is initially converted into rpm as in waveform 1 of Figure 9. The speed signal continuously increases with time. It is integrated to obtain the teta signal shown in waveform 2 and is distributed for the individual phases. The angle position is reset from 0^0 to 90^0 using modulus operator and dividing with 90 as shown in waveform 3 and is done to relate the absolute rotor position to position relative to the stroke. The cycle repeats after each 90 degrees The angle position signal for each phase are phase shifted by 30^0 as shown in waveform 3. These signals are compared with the turn on and turn off angles to generate the gate signals for different phases. When teta is between the turn on and turn off angle the gate signal is high triggering the IGBT switches of the particular phase. Waveform 4 shows

the generated signal for angle less than turn off angle, 75^0 and waveform 5 shows the signal for angle greater than turn on angle, 40^0. Waveform 6 shows the complete gate signal for angles between the turn on and turn off angles. Generated gate signals for each phase with phase shift are shown in Figure 10.

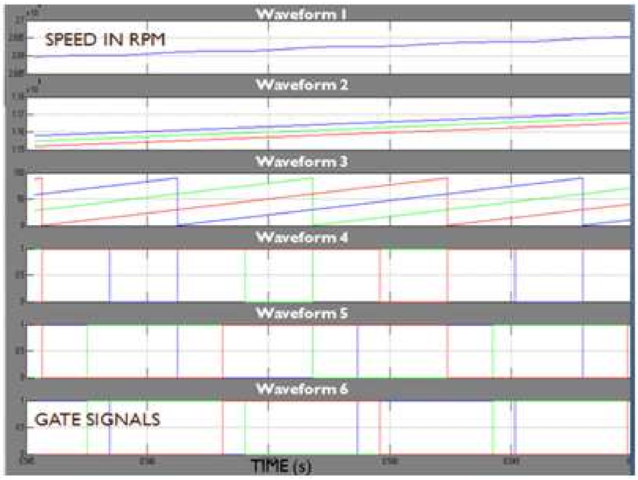

Figure 9: Different Stages of Speed Position Sensing

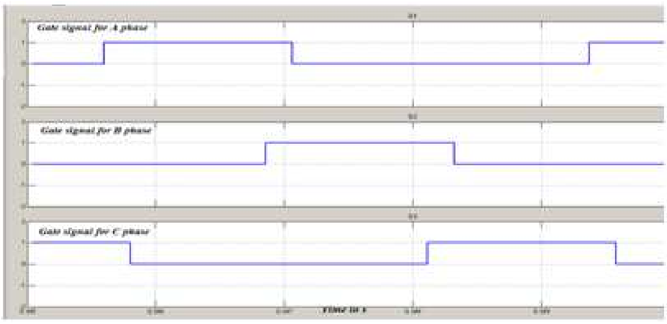

Figure 10: Gate Signals Generated Through Speed Position Sensing

Figure 11 and Figure 12 shows the motor performance parameters of the open loop control of switched reluctance motor with phase activation through speed position sensing. The output voltage has three states coinciding with the output of the R dump converter which is fed to the phase windings. The current waveform shows a peak while the phase rotor position is between the turn on and turn off angle [12].

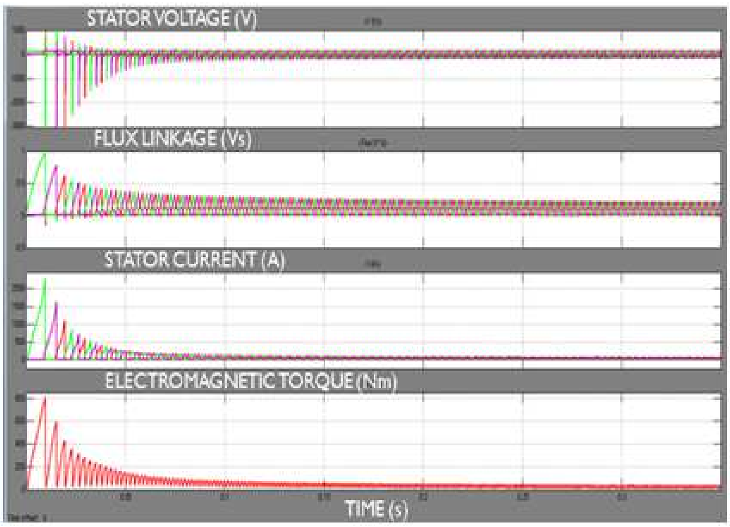

Figure 11: Motor Output Waveforms of Open Loop Control

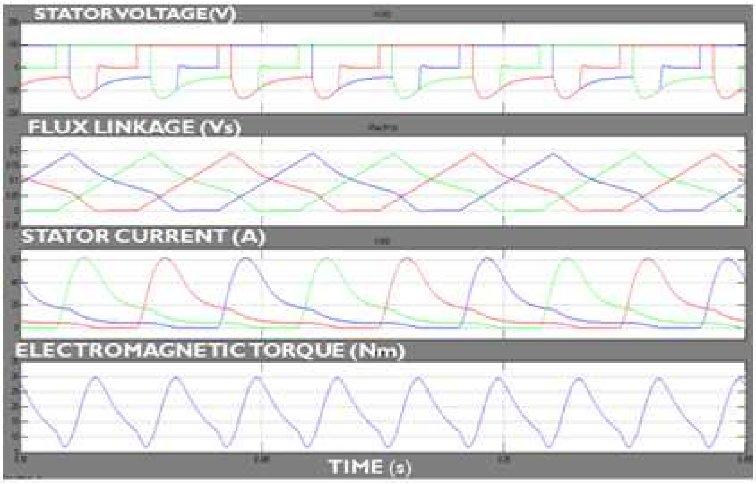

Figure 12: Motor Output Waveforms of Open Loop Control(Enlarged View)

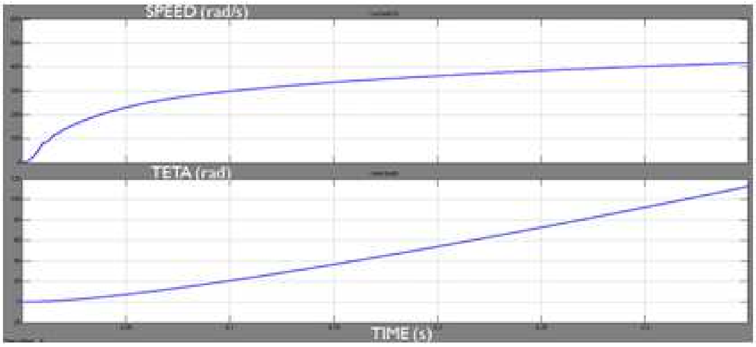

Figure 13: Speed and Teta Signals for Open Loop Control Using R Dump Converter

Speed and teta increases continuously with time as the time proceeds as in Figure 13 [13].

CONCLUSIONS

Switched reluctance motor have the attraction of simple and robust construction, high-speed and high temperature performance, low costs, and fault tolerance control capabilities large variety of schemes are available for practical applications. Asymmetrical converters are commonly used in switched reluctance drives but the R dump converter is one among the single switch per phase configuration,that is used in this paper.The open loop operation of the switched reluctance motor driven with the R dump converter is simulated using SIMULINK. The torque ripple is found to be 63.7% at no load and 47.4% at 40 Nm load.

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